CHAPTER VII

SCHEDULING CORN IRRIGATION BY UTILIZING INFRARED THERMOMETRY

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ABSTRACT

Irrigation scheduling is an increasingly important practice in the management of valuable water resources in agricultural regions where natural precipitation is supplemented by irrigation. The study reported here was aimed at evaluating the feasibility of scheduling irrigation in corn (Zea mays L.) using canopy temperature data obtained with a hand-held infrared thermometer (IRT).

Specific objectives of the study were 1) to determine if irrigation scheduling can be done using data on crop canopy temperature and, 2) to evaluate the effectiveness of a number of canopy temperature irrigation scheduling methods based on canopy temperature measurements in terms of plant responses and soil water balance.

The range in temperature of six readings made with an IRT - defined as the canopy temperature variability (CTV) - of a fully irrigated reference plot (WW) was less than 0.7 C. As the temperature difference between a stressed plot and the WW plot increased so did CTV values. This was true until a certain stress level was reached at which point CTV values leveled off. The onset of stress can, therefore, be identified when CTV exceeds 0.7 C but, it appears, that the temperature difference between well-watered and stressed vegetation provides a better measure of stress severity than do CTV values.

Two kinds of irrigation initiating procedures were studied.

In one procedure irrigation is initiated when the range of six measurements in a plot reached 0.8 C (0.8 CTV). The second procedure consists of a comparison of the difference between the average canopy temperatures of the WW plot and of the plot to be scheduled. Irrigation was initiated when plot temperatures became either 1.0 (1SMW) or 3.0 C (3SMW) warmer than the well-watered plot. At least two irrigations were called for in each plot scheduled on the basis of temperature.

A total of 26 cm of water was applied to the well-watered plot while the 0.8 CTV plot received only 12 cm. By the end of the growing season almost all available water had been extracted from soil in the temperature scheduled plots but the soil profile was still almost full in the well-watered plot. This suggests that soil water was more effectively used during the growing season in the temperature scheduled plots.

Grain yields (Y) were reduced in the order of increasing water stress as follows:

$$Y_{WW} > Y_{0.8CTV} > Y_{1SMW} > Y_{3SMW} > Y_{DL}$$

Compared to the well-watered plot, yields of grain in the CTV treatment were reduced by about 5% but not significantly so, with respect to the well-watered plot. Grain yields in the other temperature scheduled plots were significantly reduced below the yields of the well-watered plot, but only about 5 to 6 cm of irrigation was applied.

INTRODUCTION

Irrigation scheduling has become important in water management schemes for cultivated lands in subhumid, semiarid and arid

regions. It has been suggested that crop temperature measurements may be used to schedule irrigations. Tanner (1963) was among the first to use infrared thermometry to measure canopy temperature differences caused by water stress. He found a maximum temperature difference of 3 C between irrigated and unirrigated potatoes (Solanum tuberosum). Increases in temperature appeared to be due to an observed stomatal closure.

Increases in canopy temperature have been correlated with leaf relative turgidity (Wiegand and Namken, 1966), soil water content (Millar, et al. 1971 and Bartholic, et al. 1972) and leaf water potential (Erhler, et al. 1978 a, b).

Heermann and Duke (1978) reported a linear relationship between grain yields of corn and increases in canopy temperature due to stress. They observed that grain yields did not begin to decline until the average growing season temperature of the stressed plants exceeded the temperature of well-watered plants by 1.5 C. Every additional degree rise reduced yields by 15%. These relationships were obtained from temperature measurements made with an infrared thermometer held in a vertical position over the crop. When the IRT was held at an oblique angle, the numerical relationships changed slightly.

Gardner (1980) correlated corn yields with differences in canopy temperature between stressed and non-stressed plants grown under several irrigation regimes. Summation of these mid-day differences in daily temperature during the pollination and grainfill stages was used successfully to predict grain yield to within 10% of actual values.

Aston and van Bavel (1972) suggested that the onset of water

deficit conditions could be detected by comparing the canopy temperature of a stressed plot with that of a well-watered reference plot. They also theorized that a field might serve as its own reference because of differing soil water contents due to non-uniform irrigation application and infiltration rate. Because of such inhomogeneity, they suggested, the variability in crop temperature measured at several locations within the same field may indicate the onset of water stress.

Millard et al. (1978) found canopy temperature variability in a wheat field, 72 m x 15 m in size, as detected by an airborne thermal scanner, was as great as 5 C. They cautioned that spot measurements of canopy temperatures made near the ground may not be indicative of overall field conditions. According to Nixon et al. (1973) the practice of using average canopy temperature of water-stressed plots above that of non-stressed plots in order to characterize water stress is not strictly valid. This is because of the variations in canopy temperature that occur within a field. They observed that the canopy temperature variability within an 800 m wide field of cotton increased as soil water was depleted, although an elevation in average canopy temperature was not detected. They suggested that canopy temperature variability indicated the presence of spots with adequate or inadequate water in a field. This temperature variability, therefore, could be used in irrigation management.

In Chapter V it was reported that in fully irrigated plots of corn the standard deviation of mid-day canopy temperatures was about 0.3 C. In non-irrigated plots, it was as great as 4.2 C. We concluded that plots which exhibited an increase in the stan-

dard deviation above 0.3 C indicated were in need of irrigation.

The objectives of the study reported here were 1) to determine whether irrigation can be effectively scheduled using canopy temperature data obtained with a handheld infrared thermometer (IRT) and 2) to evaluate the influence of irrigations so scheduled on plant growth and on soil water balance.

MATERIALS AND METHODS

This study was conducted during the summer of 1979 in the solid set irrigation area at the Sandhills Agricultural Laboratory. The Laboratory is located 40 miles north of North Platte, near Tryon in McPhearson County, Nebraska (41° 37' N, 100° 50' W, 975 m above m.s.l.). The soil has been tentatively classified as Valentine fine sand, loamy substratum phase (order Entisol). It is characterized by a sandy surface with buried clay horizons. These horizons may have water holding capacities 3.5 times as great as the overlying sand (Lewis, 1976).

Five plots were planted to corn (cv Pioneer 3901) on May 19 in 76 cm wide N-S rows at a rate of 69,190 plants per hectare. Plots were later thinned to 64,250 plants per hectare. Each plot measured 28.3 m E-W by 56.6 m N-S (Fig. 1). A 9 m wide grass strip bordered the plots to the west. The area bordering the other three sides of the experimental area was planted to corn which was fully irrigated during the entire season. Each plot was irrigated with sprinklers about 2 m above the ground and spaced 18.9 m apart N-S on the borders. A small path about 3 m in width was left between the center of the plots to allow for access to instrumentation.

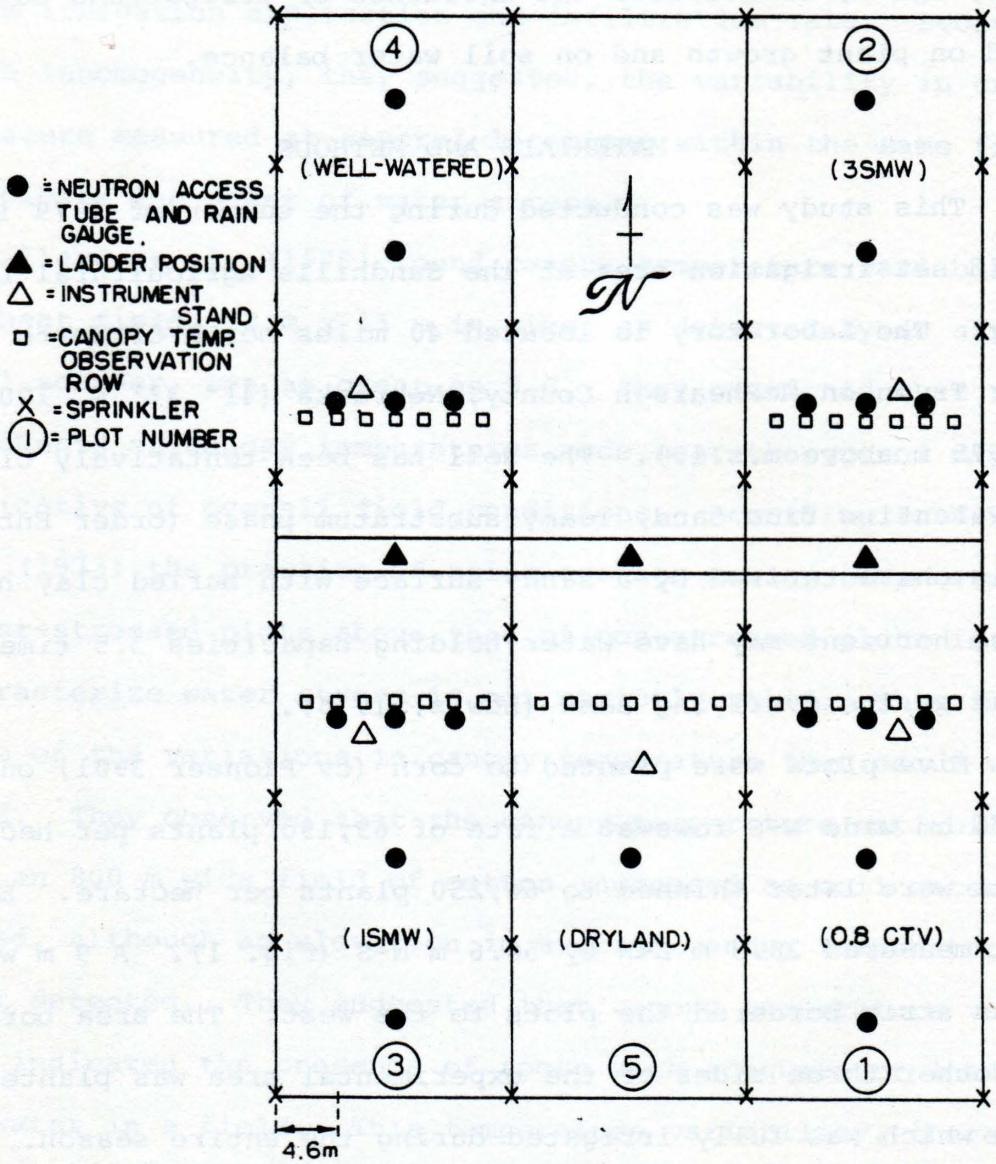

Fig. 1. Detail of the five experimental plots at the University of Nebraska Sandhills Agricultural Laboratory.

Plots were harvested on October 19 for grain yield comparisons. Ten rows were selected for harvest in each plot. Seven of these included the rows in which infrared measurements had been made. Harvest rows were 5.9 m in length. Ears were harvested by hand and shelled mechanically.

During the season canopy temperatures were measured with a handheld infrared thermometer.[1] The instrument has a field of view of 5°, a sensing window of 10.5-12.5 μm, a resolution of 0.1 C, and a guaranteed accuracy of 0.5 C. The instrument was calibrated frequently using a method described by Blad and Rosenberg (1976). The output of the IRT agreed well with the temperature of a blackbody immersed in a controlled temperature water bath over a wide range of temperatures. The instrument performance was frequently checked by comparing the IRT reading to the temperature of a water bath.

Canopy temperature measurements began on July 11 and ended on September 15. Canopy cover was greater than 85% during this period. Seven spot measurements were made in each plot daily at about 1400 hours solar time. Measurements were made from atop a 4 meter portable ladder positioned in front of row 12 at the middle of each plot. The IRT was aimed consecutively at rows 3, 6, 9, 12, 15, 18 and 21. The reading from row 12 was discarded because the IRT "view" of that row included the exposed soil, leading, often, to excessively high temperature readings. At the other angles of view across the plot, canopy cover appeared to be 100% complete.

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[1]Telatemp Corp., P.O. Box 5160, Fullerton, CA (model AG-42).

The IRT was pointed in a southerly direction for observation of plots 1, 3 and 5. When observation of plots 2 and 4 were made, the IRT was pointed in a northerly direction. Differences in corn canopy temperature as a function of direction were small enough to be neglected (see Chapter IX and Fuchs et al., 1967). The area of vegetation viewed from the ladder was about 0.2 m^2 and was elliptical in shape. The major and minor axes were about 1 and 0.6 m, respectively.

The parameters chosen as irrigation initiators were designed to create a range of growing conditions from ample water supply to drought. Treatments are detailed in Fig. 1. Plot 5 was designated as a "dryland" control plot (DL) and received only naturally occurring rainfall. Plot 4 was designated as a "well-watered" control plot (WW). It was irrigated weekly to refill the soil reservior to field capacity. The amount of water applied at each weekly irrigation to plot WW was computed as the amount needed to return the soil to field capacity. Weekly irrigation requirements were not corrected for sprinkler application efficiency. Water was applied by sprinklers until rain gauge catch at the canopy top indicated that the gross irrigation requirement had been satisfied. Deep percolation was, thereby, avoided.

Irrigations of plots 1 through 3 were determined on the basis of on canopy temperatures sensed by the IRT. Irrigation scheduling techniques were designed to simulate the conditions under which a farmer might use an IRT.

Irrigation of plot 1 was initiated when the canopy temperature variability (CTV) within that plot was at least 0.8 C or

greater (0.8 CTV). CTV is defined as the range (maximum minus minimum) of all IRT sensed canopy temperatures within a plot during a measurement period.

Treatments for plots 2 and 3 were based on comparison of the average canopy temperature of these plots with the average canopy temperature of the well-watered plot (plot 4). The average canopy temperature was computed by averaging all IRT sensed canopy temperature measurements in a single plot. Irrigation water was applied when the average canopy temperatures of plots 3 and 2 became, respectively, 1.0 and 3.0 C warmer than the average canopy temperature of plot 4. These treatments were termed 1SMW and 3SMW. SMW (Stressed Minus Watered) is defined as the difference between the average canopy temperature of a water stressed plot and that of a well-watered plot. The amount of water applied to each temperature scheduled plot ranged from 1.0 to 3.0 cm but was never greater than the weekly evapotranspiration (ET) from plot 4.

Soil water status was determined with a neutron moisture probe[2] on a weekly basis and more frequently as circumstances permitted. Five access tubes were installed to a depth of 1.52 m in each of plots 1 through 4. Plot 5 had only one access tube (see Fig. 1 for location of access tubes). Sampling depth increments for neutron probe measurements were 0-23, 23-46, 46-76, 76-107, 107-137, 137-168 cm. At at each access tube, two one-minute standard count readings were taken and two fifteen-second readings were taken at each depth.

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[2]Troxler Electronic Laboratory, Inc., Raleigh, NC (model 2651).

RESULTS AND DISCUSSION

The need for irrigation was indicated at least twice in each of the temperature scheduled treatments. The dates of each irrigation and the amounts of water applied are given in Table 1. The daily values of canopy temperature variability from the CTV scheduled plot are shown in Fig. 2. The temperature differences between the stressed and well-watered plots for the 1SMW and the 3SMW plots are shown in Figs. 3 and 4, respectively. All data plotted are for clear days after canopy cover became 85% complete.

The CTV plot received 12.7 cm of water in five separate applications during each of the three major stages of phenological growth. The threshold temperature of 1.0 C was not reached in the 1SMW plot until the pollination stage. That plot received a total of 5.4 cm of irrigation water - 2.6 cm in a single application in the pollination stage and 2.8 cm more from two applications during the grainfill stage.

The 3SMW plot was irrigated in all stages of growth although threshold canopy temperatures indicated the need for irrigation only twice. The 3SMW plot was unintentionally irrigated on July 3 and again on August 3. Irrigations were scheduled on the basis of canopy temperature parameters during the grainfill period on August 12 and 24. A total 6.2 cm of irrigation water was applied to the 3SMW plot.

The CTV and SMW temperatures were reduced in all cases following irrigation. CTV in the 0.8 CTV plot was reduced from greater than 0.8 C to a value between 0.5 and 0.7 C. CTV in the well-watered plot did not depend upon irrigation. For example, following an irrigation during the pollination period, CTV

Table 1. Dates of irrigation and amounts of water applied to each plot.

	Irrigation Treatment				
Dates	WW (cm)	0.8CTV (cm)	1SMW (cm)	3SMW (cm)	DL (cm)
July 3				1.2	
July 13	3.3				
July 15		3.2			
July 25	5.4	4.8			
August 3				3.7	
August 4			2.6		
August 7	6.1	2.6			
August 11		1.0	1.2		
August 12				1.5	
August 14	4.2				
August 22	6.4				
August 23			1.6		
August 24		1.1		1.0	
September 6	2.9				
Water Applied					
irrigation	28.2	12.7	5.5	6.2	--
rainfall	27.5	27.5	27.5	27.5	27.5
total	55.7	40.2	33.0	33.7	27.5

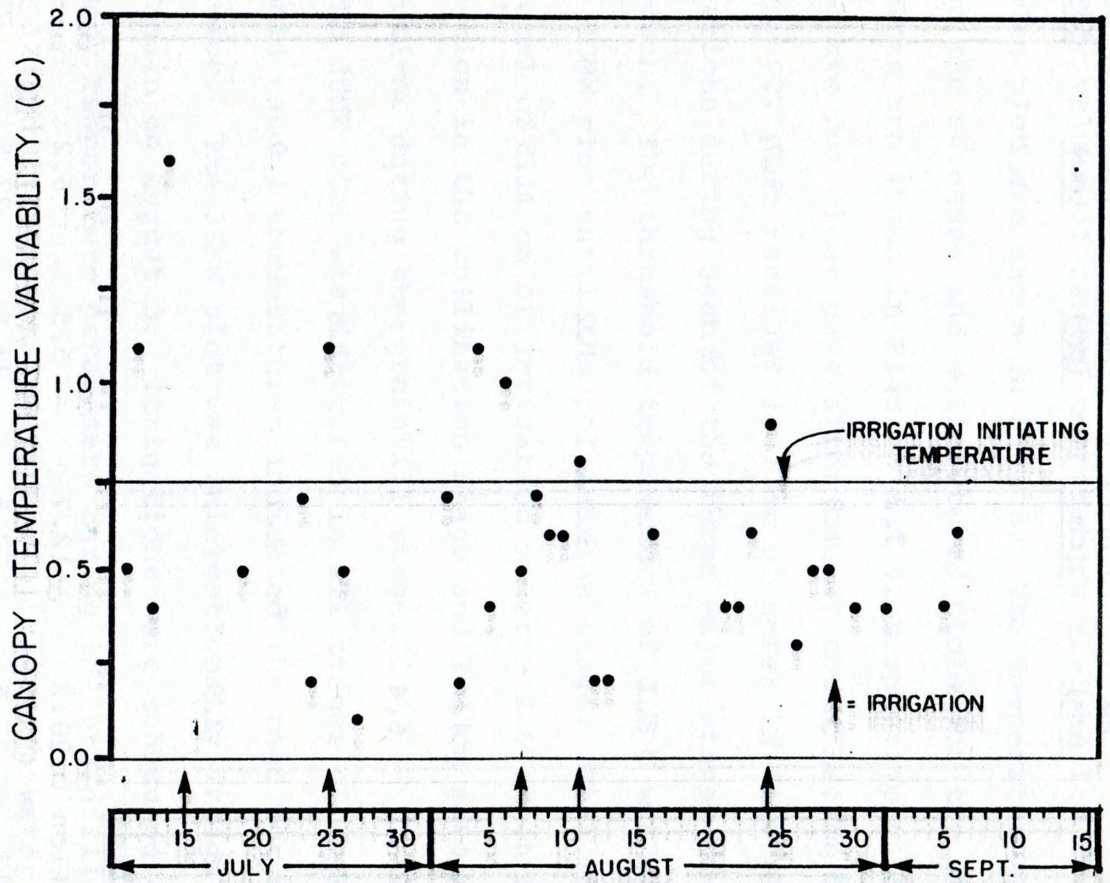

Fig. 2. Canopy temperature variability for the CTV plot throughout the growing season.

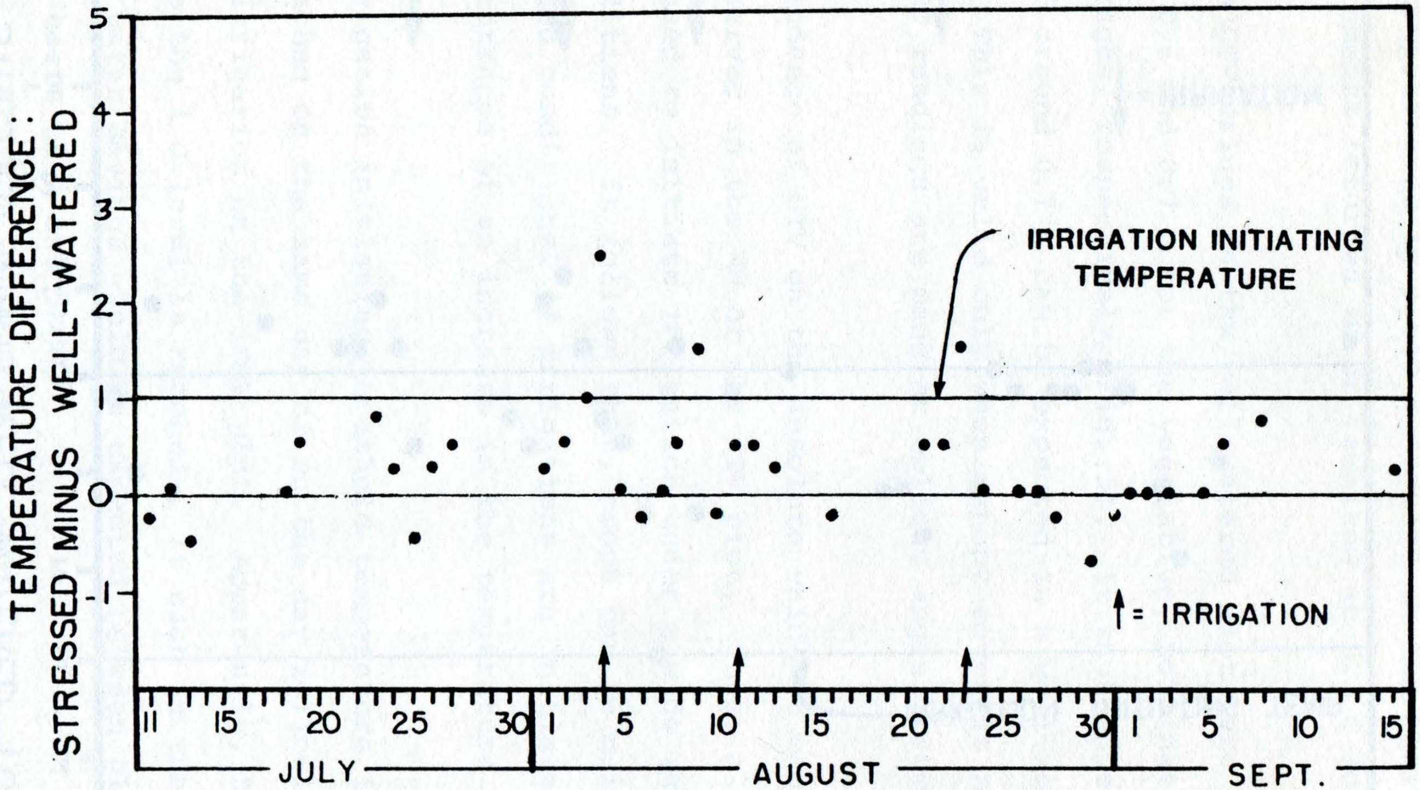

Fig. 3. Canopy temperature differences between the 1SMW plot and the well-watered plot.

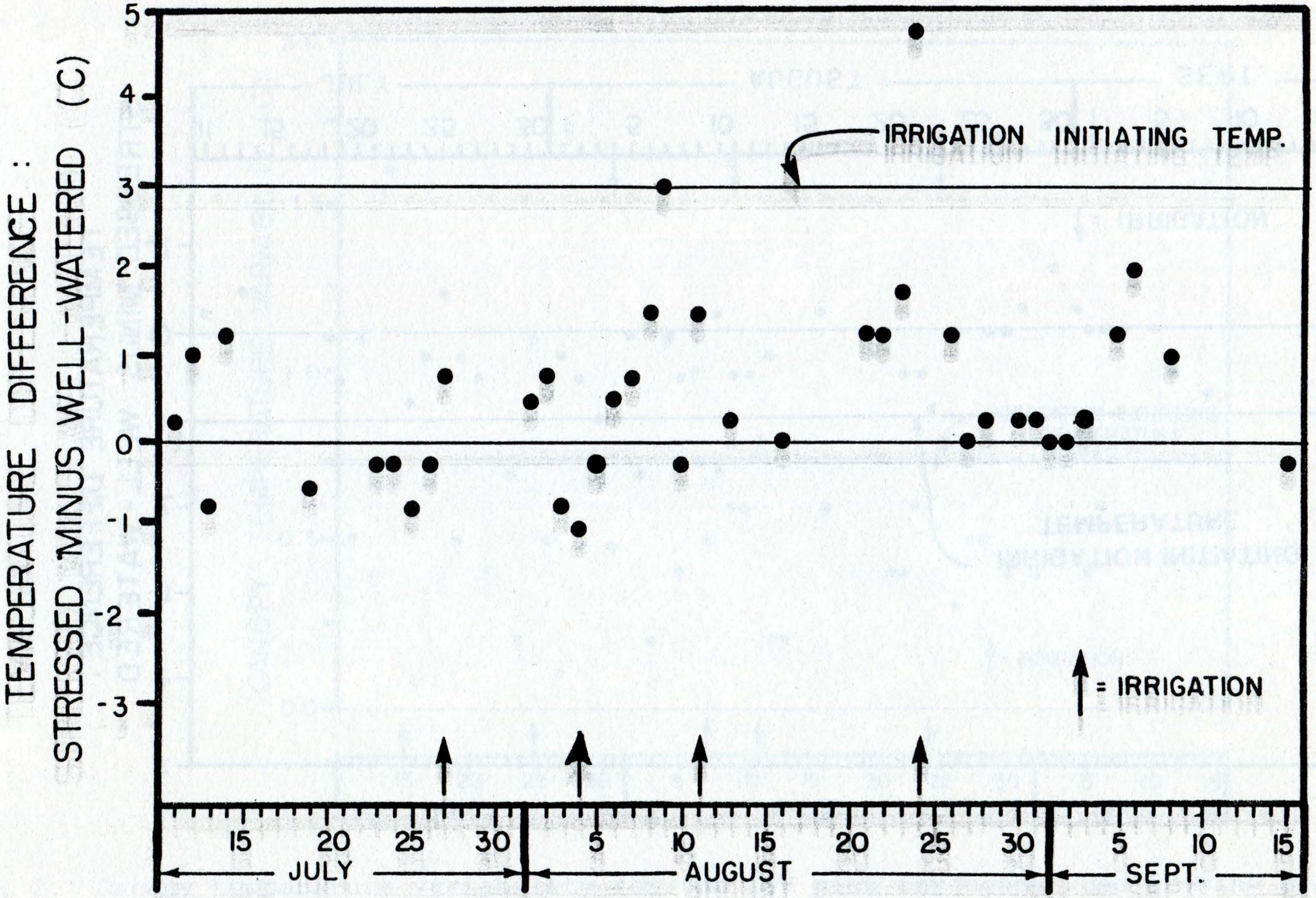

Fig. 4. As in Fig. 3 for the 3SMW plot.

remained at about 0.7 C. These results agree quite well with those of Gardner (1980) who reported that the standard deviation of mid-day canopy temperatures in plots scheduled on the basis of neutron probe measurements returned to or remained at 0.3 C following an irrigation.

Maximum CTV values in the well-watered plot were approximately 1.0, 0.6 and 0.7 C for the vegetative, pollination and grainfill stages, respectively (Fig. 5). It thus appears that a CTV value of around 0.7 C can be expected in a well-watered crop at mid-day. This is valid only when canopy cover is nearly complete and IRT readings are made at oblique angles between about 20° to 40°.

No dependence of CTV on the absolute value of canopy temperature was observed in the WW or the CTV plot. Thus, a specified CTV can be used to initiate irrigation under a wide range of weather conditions. It follows that, crops can be maintained in a well-watered conditions, if irrigations are initiated immediately after occurrence of an increase in the temperature variability above 0.7 C.

The irrigation initiating threshold temperature for the 3SMW plot was reached on the same day or on the day following the initiation of irrigation on the 1SMW plot. Apparently, SMW increases rapidly once the 1 C level is reached. If such is the case, no significant water savings would be expected between plots scheduled on the basis of 1 and 3SMW.

The CTV plot required less than half the amount of water required by the WW plot during the entire season. This suggests that using canopy temperature variability as a parameter to initiate

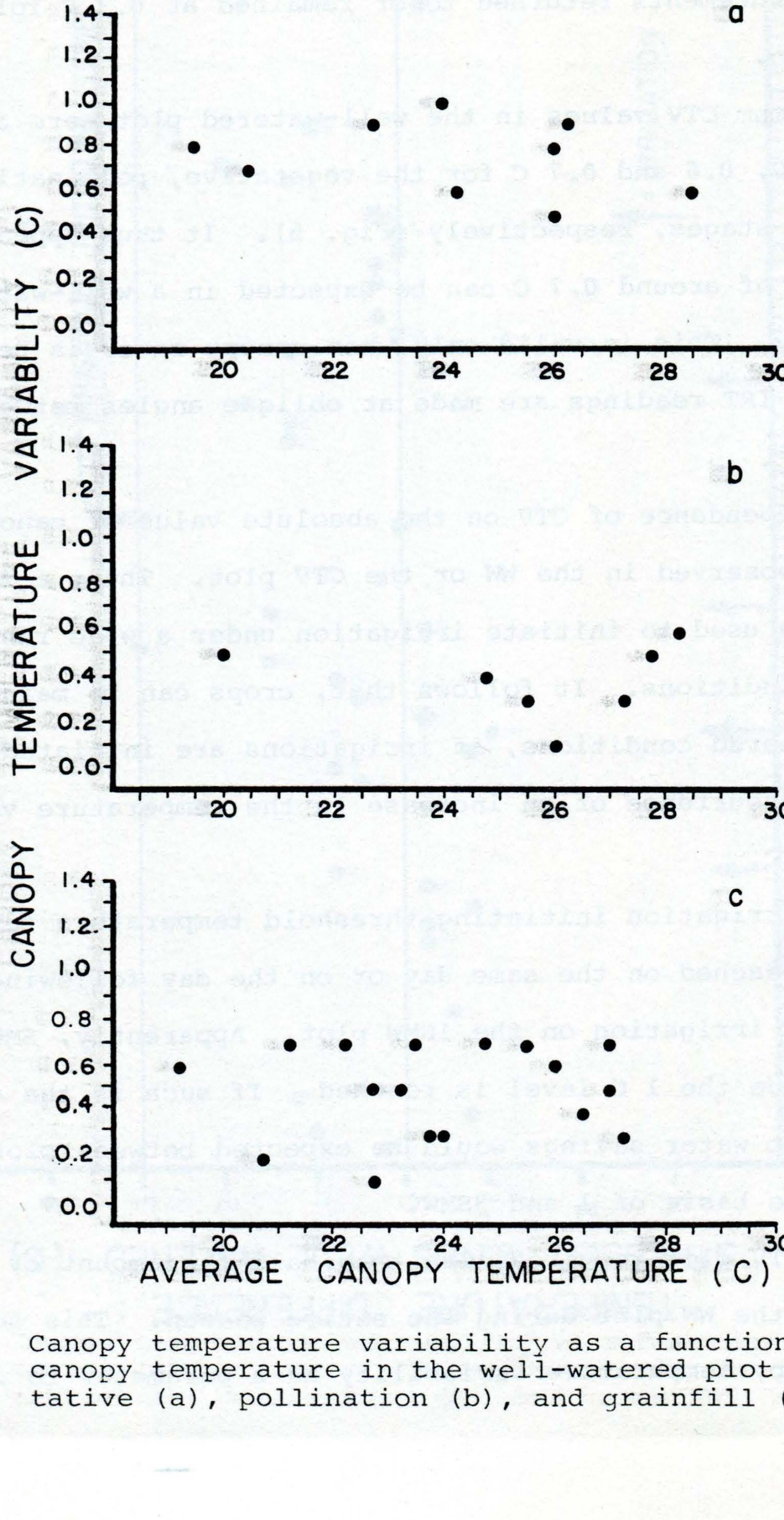

Fig. 5. Canopy temperature variability as a function of average canopy temperature in the well-watered plot for the vegetative (a), pollination (b), and grainfill (c) periods.

irrigation has the potential for significant water savings and for improved efficiency in the use of available soil water.

CTV and the SMW temperature elevations were found to be interrelated (Table 2). No significant relationships existed in any plot during the vegetative stage, probably because of a general lack of stress during this period. The relationship between CTV and SMW in the 1SMW, the 3SMW and the DL plots was significant. The relationship with 1SMW was significant at the 99% level in both the pollination and grainfill stages. The relationship with 3SMW showed significance at the 95% level during the grainfill stage. The relationship with DL showed significance at the 90% level during the grainfill stage. No other correlations were obtained. An example of the relationship between CTV and 1SMW for the grainfill period is shown in Fig. 6.

The regressions indicated that the CTV parameter was more sensitive to water stress than were the SMW parameters. When water stress was mild, SMW was at or very near 0.0 C, while CTV fluctuated between 0.0 and 0.7 C. As water stress increased, both SMW and CTV increased. As the stress became increasingly severe, SMW increased rapidly while CTV began to level off. This accounts for the lower level of significance that was observed for the 3SMW and the DL treatments than was obtained for the 1SMW treatment.

Thus it appears that canopy temperature variability can be used to signal the onset of plant water stress but the severity of plant water stress is probably best indicated by the magnitude of the elevation in average canopy temperature above that of a well-watered reference plot.

Table 2. Summary of regression statistics for comparison of stressed minus well-watered canopy temperature difference (SMW) with canopy temperature variability (CTV) in all growth stages. a, b and c denote significance at 99, 95 and 90 percent, respectively. Average values of CTV and SMW are also listed.

	Irrigation Treatment			
	0.8CTV	1SMW	3SMW	DL
Vegetative				
R^2	0.001	0.035	0.001	0.246
slope	0.03	0.12	0.01	-0.09
y intercept	0.68	0.76	0.26	0.43
avg SMW (C)	-0.3	0.2	0.1	-0.2
avg CTV (C)	0.7	0.8	0.3	0.5
Pollination				
R^2	0.078	0.667a	0.197	0.230
slope	-0.09	0.71	-0.12	0.38
y intercept	0.57	0.68	0.29	0.76
avg SMW (C)	-0.2	0.6	0.5	0.5
avg CTV (C)	0.6	1.1	0.3	0.9
Grainfill				
R^2	0.00	0.440a	0.317b	0.160c
slope	0.00	0.65	0.10	0.24
y intercept	0.48	0.76	0.24	1.01
avg SMW (C)	-0.1	0.2	1.3	1.2
avg CTV (C)	0.5	0.9	0.2	1.2

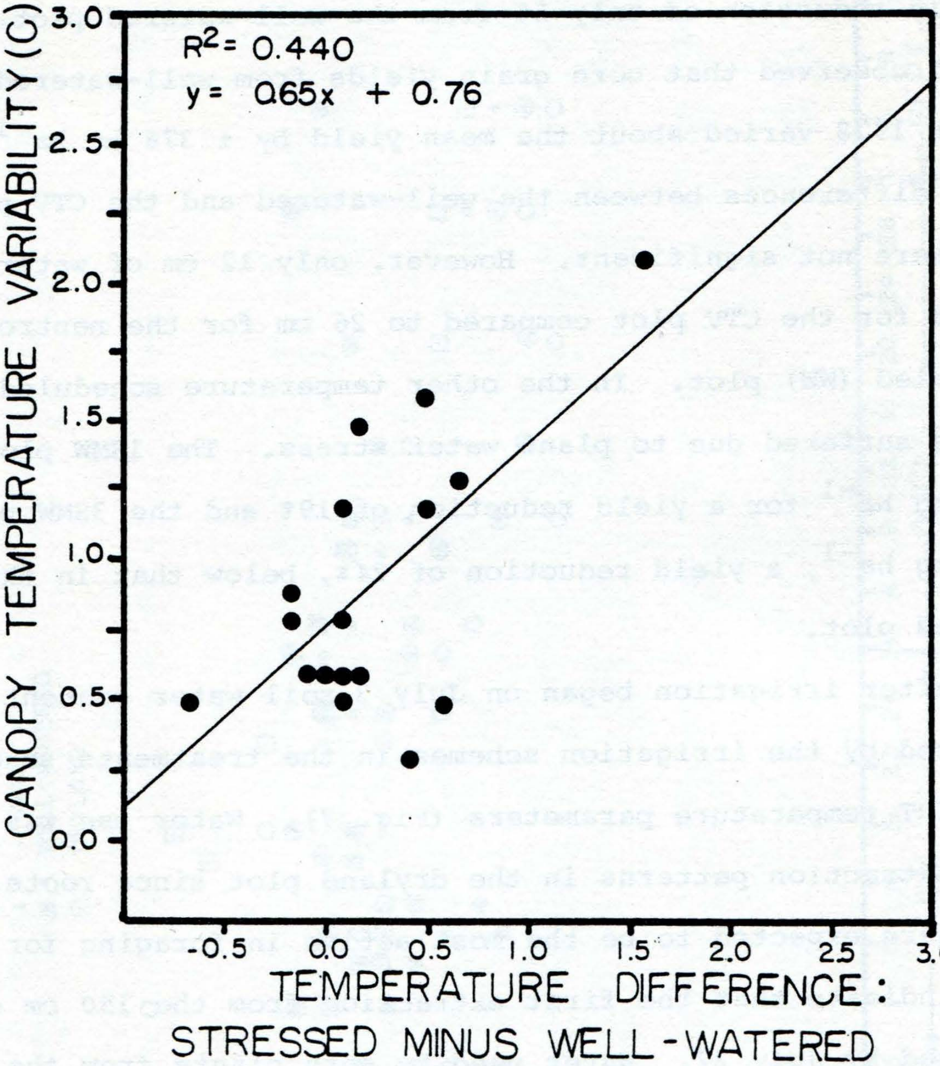

Fig. 6. Comparison of the canopy temperature difference between the SMW plot and the well-watered plot and the canopy temperature variability of the 1SMW plot. Data were obtained during the grainfill period.

The maximum grain yield of 7575 kg ha^{-1} was obtained from the well-watered plot. The minimum yield of 4933 kg ha^{-1} was from the dryland plot. This difference represents a yield reduction of 35%. Grain yields from the temperature scheduled plots fell between these extremes. The CTV plot yielded 7202 kg ha^{-1}. This is a yield reduction of only 5% from the well-watered plot. Gardner (1980) observed that corn grain yields from well-watered plots at SAL in 1978 varied about the mean yield by ± 376 kg ha^{-1}. Thus yield differences between the well-watered and the CTV plot in 1979 were not significant. However, only 12 cm of water was required for the CTV plot compared to 26 cm for the neutron probe scheduled (WW) plot. In the other temperature scheduled plots, yields suffered due to plant water stress. The 1SMW plot yielded 6197 kg ha^{-1} for a yield reduction of 19% and the 3SMW plot yielded 5815 kg ha^{-1}, a yield reduction of 24%, below that in the well-watered plot.

After irrigation began on July 3 soil water content was influenced by the irrigation schemes in the treatments scheduled with IRT temperature parameters (Fig. 7). Water use was compared with extraction patterns in the dryland plot since roots in that plot were expected to be the most active in foraging for water. Data indicate that the first extraction from the 150 cm depth occurred by July 27. Water used by corn plants from the 150 cm level in the DL plot was small--only 2 cm for the entire season.

Differences in the soil water content due to irrigation treatment did not appear until after the beginning of the pollination period. The general pattern that emerged after July 23 was one in which the average volumetric water content was highest

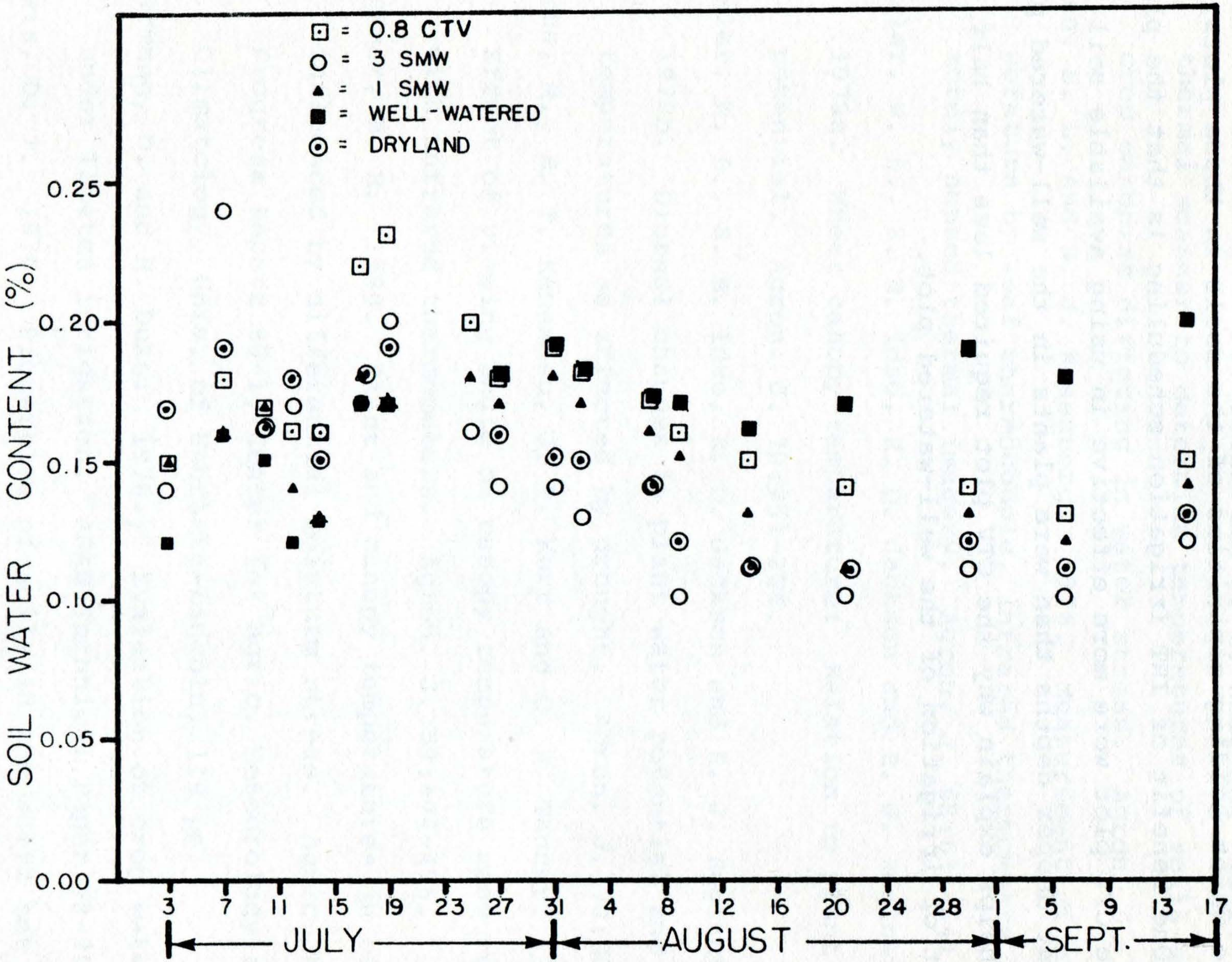

Fig. 7. Pattern of soil water content (% by volume) for the depths of active water extraction in each plot. Root depths ranged from 0-60 cm on July 3 to 0-150 cm on July 25 and for the duration of the study.

in the WW plot, followed in order by the 0.8 CTV, the 1SMW, the DL and the 3SMW plots. The reason that the 3SMW plot showed a small but consistent pattern of a lower water content than did did the dryland plot is unknown but probably reflects differences in the water holding capacities of the soils in these plots.

One benefit of IRT irrigation scheduling is that the plants in the CTV plot were more effective in using available soil moisture at deeper depths than were plants in the well-watered plot. This helps explain why the CTV plot required less than half the amount of irrigation of the well-watered plot.

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